

# Hale Crater - Ancient Water Science, Contemporary Water Resource

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# Motivation

- Mining a football field worth of hydrated material
- Go to a natural martian spring (RSL)



2500 km

# Chryse and Acidalia Planitia

## Valles Marineris

## Tropical Highlands

Thin dark  
RSL-like features

Incremental  
lengthening

Recurrence

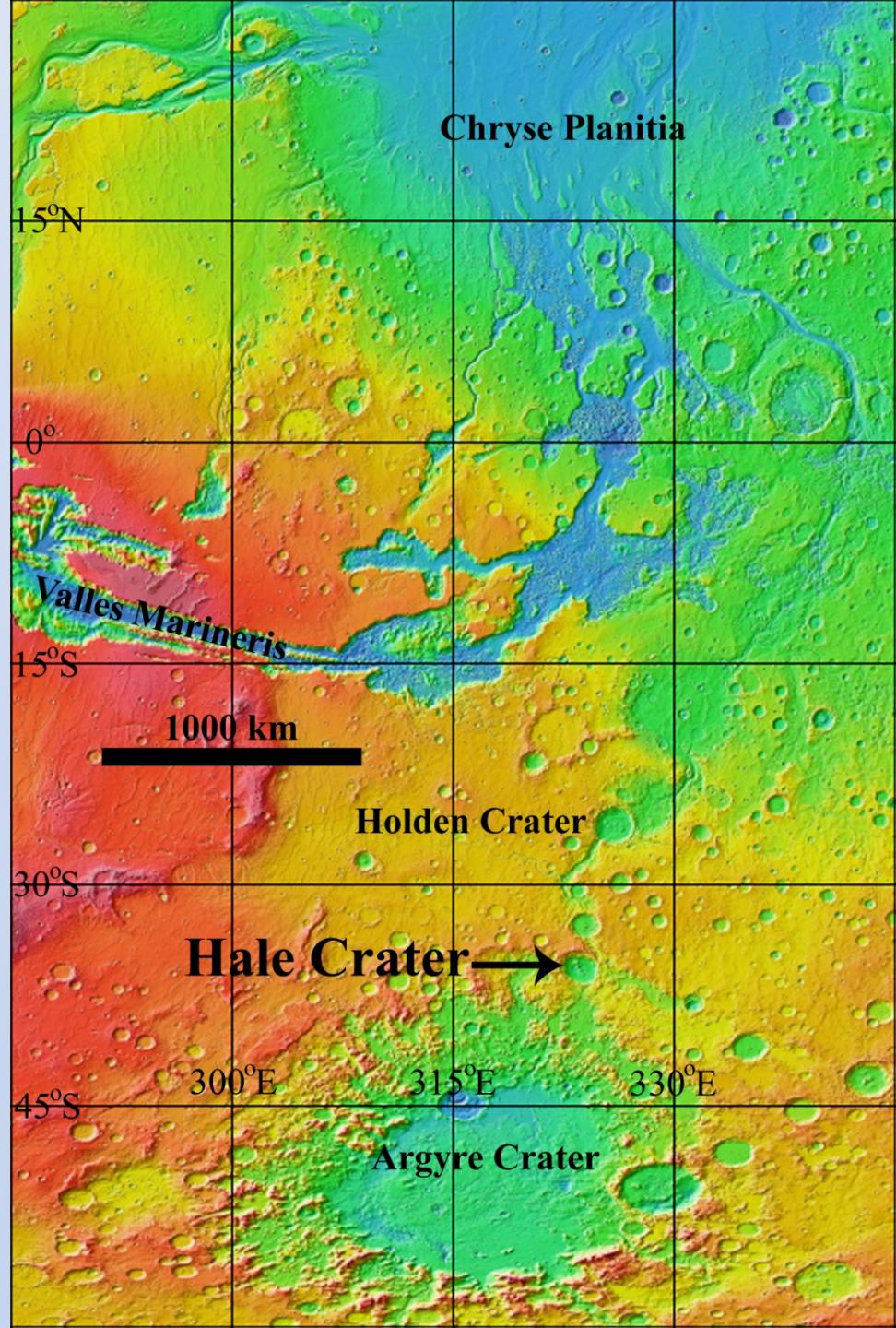
Fading

Hale Crater

200 RSL sites  
51 confirmed

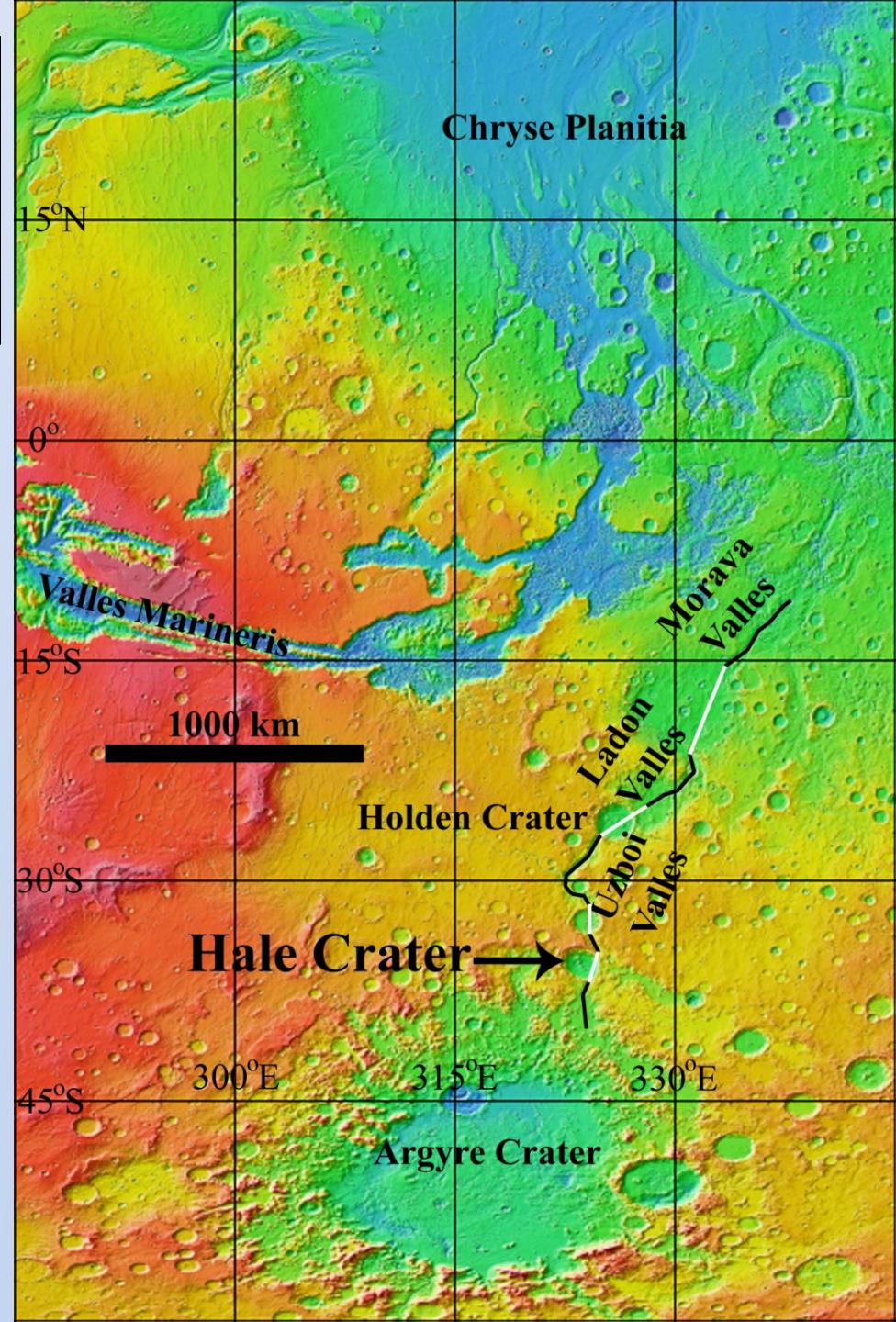
# Argyre

- A *significant* stratigraphic event
- Middle Noachian 3.93 Ga (Robbins et al., *Icarus*, 2013)
- Surrounding features mapped relative to Argyre



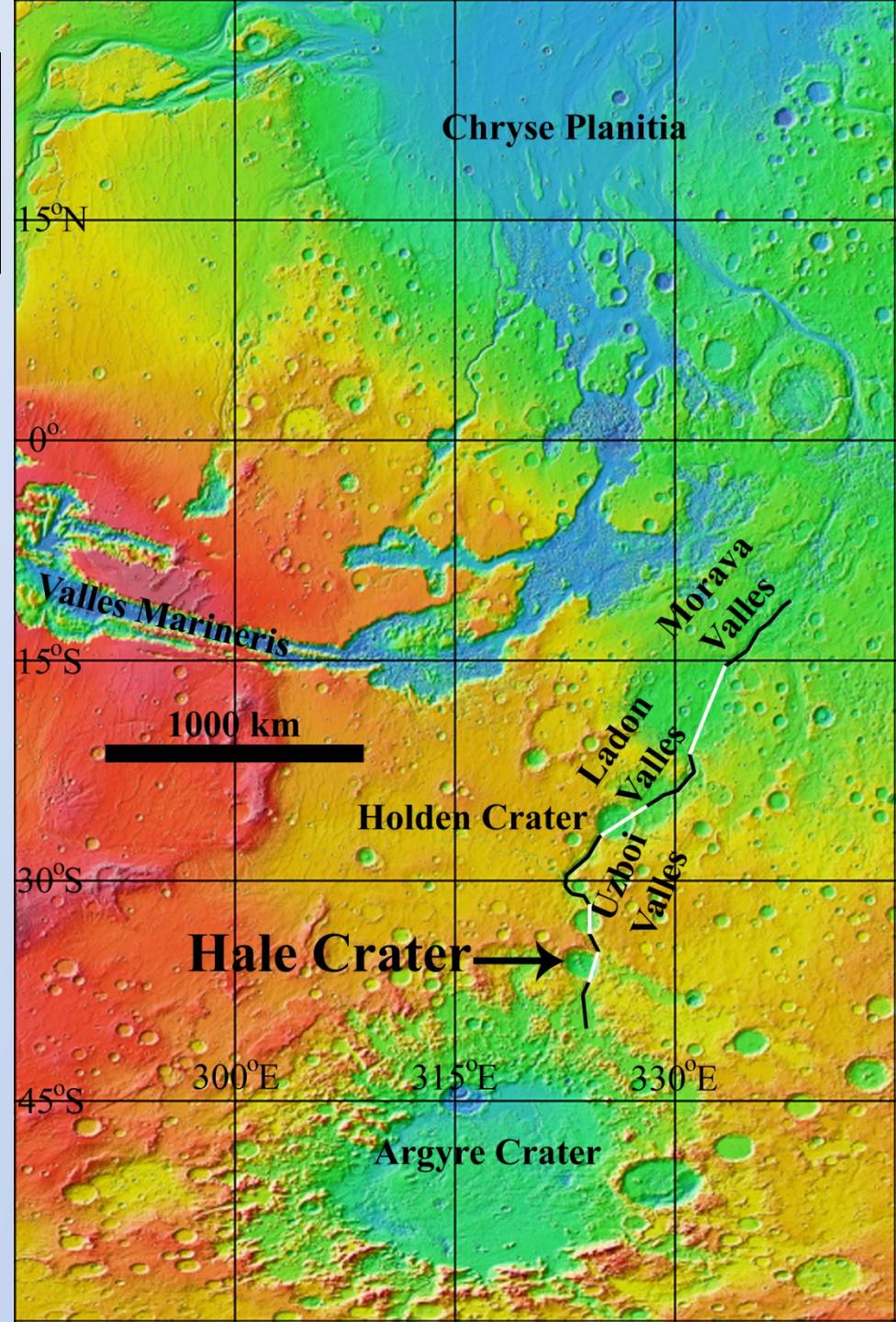
# Uzboi-Ladon-Morava (ULM) Valles outflow system

- ULM – transported large volumes of water ( $150,000\text{--}450,000 \text{ m}^3/\text{s}$ ) during late Noachian to early Hesperian (Grant and Parker, *JGR*, 2002)
- ULM source is unknown



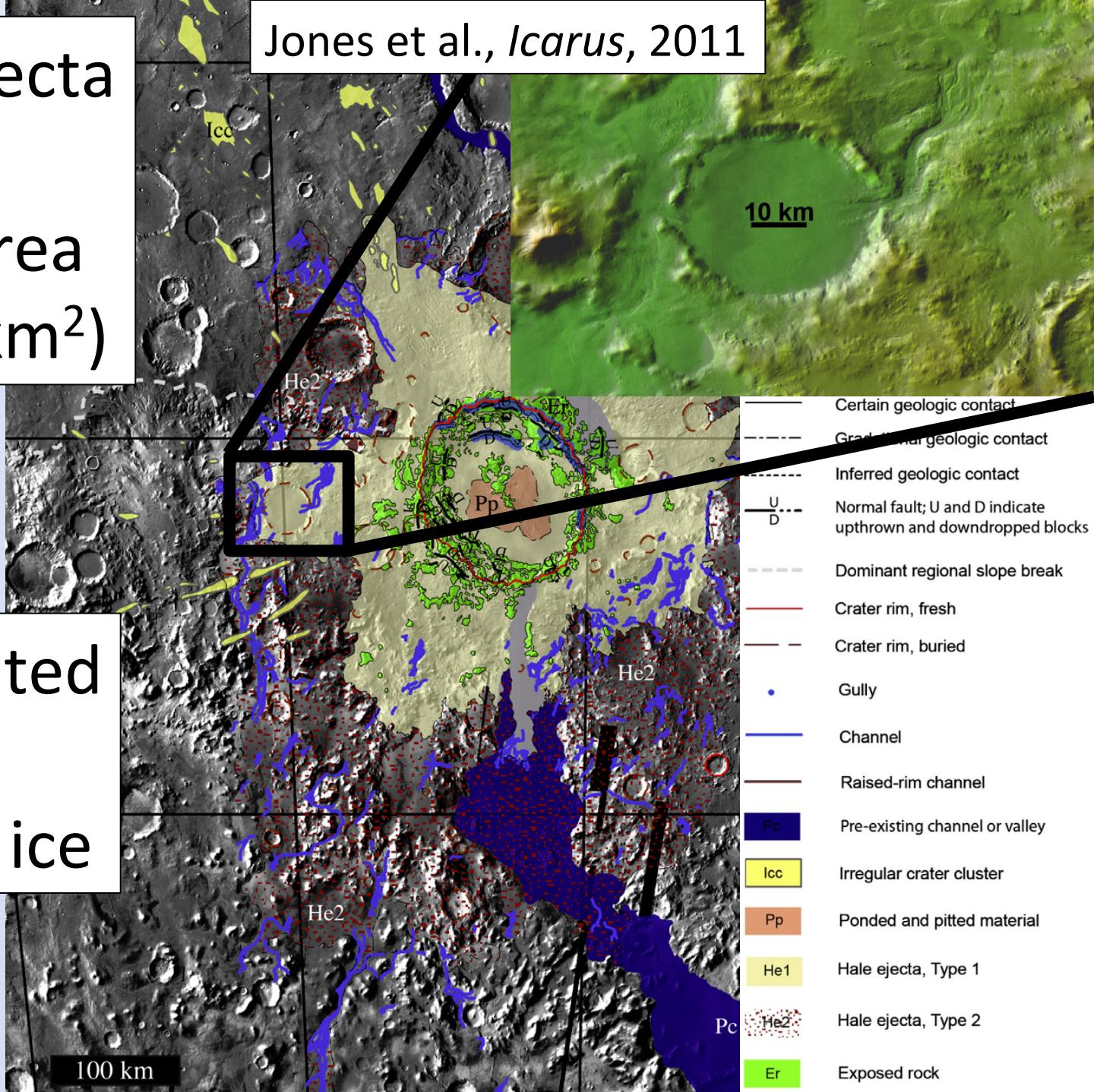
# Formation of Hale Crater

- Amazonian crater (>1 Ga) postdates ULM



Fluidized ejecta  
over an  
extensive area  
( $>200,000 \text{ km}^2$ )

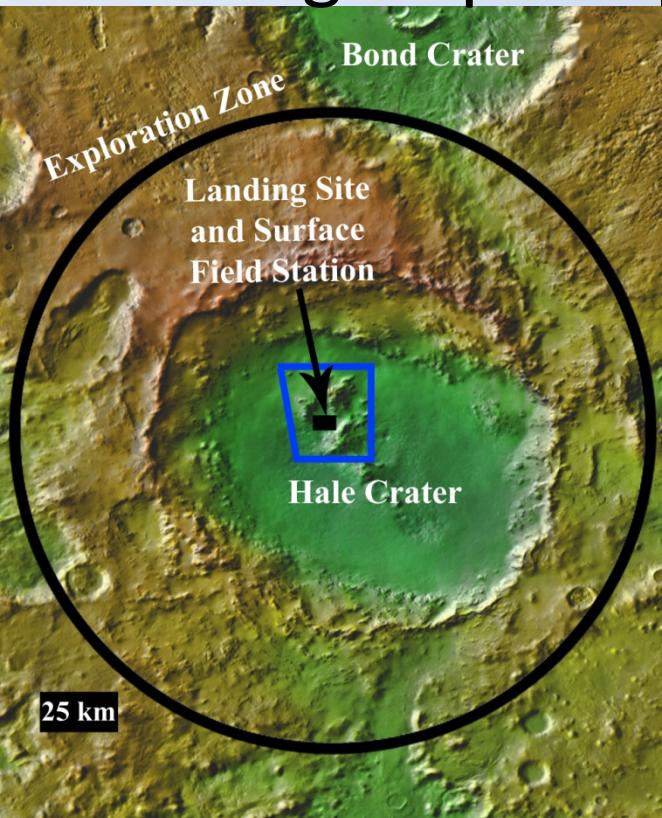
Jones et al., *Icarus*, 2011



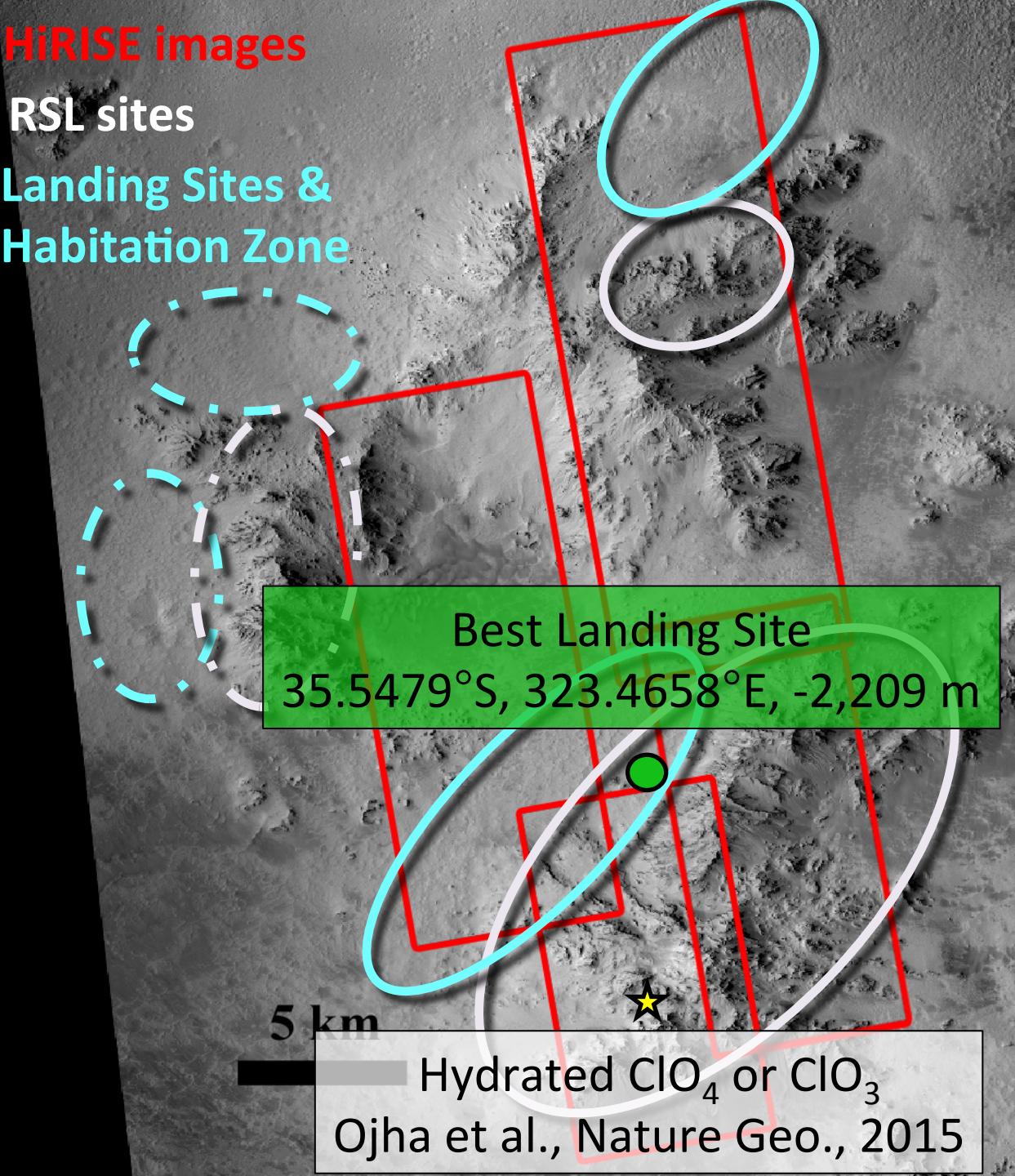
Impact melted  
 $10 \text{ km}^3$  of  
subsurface ice

# Hale LZ/HZ

- RSL prefer NW- and W-facing slopes

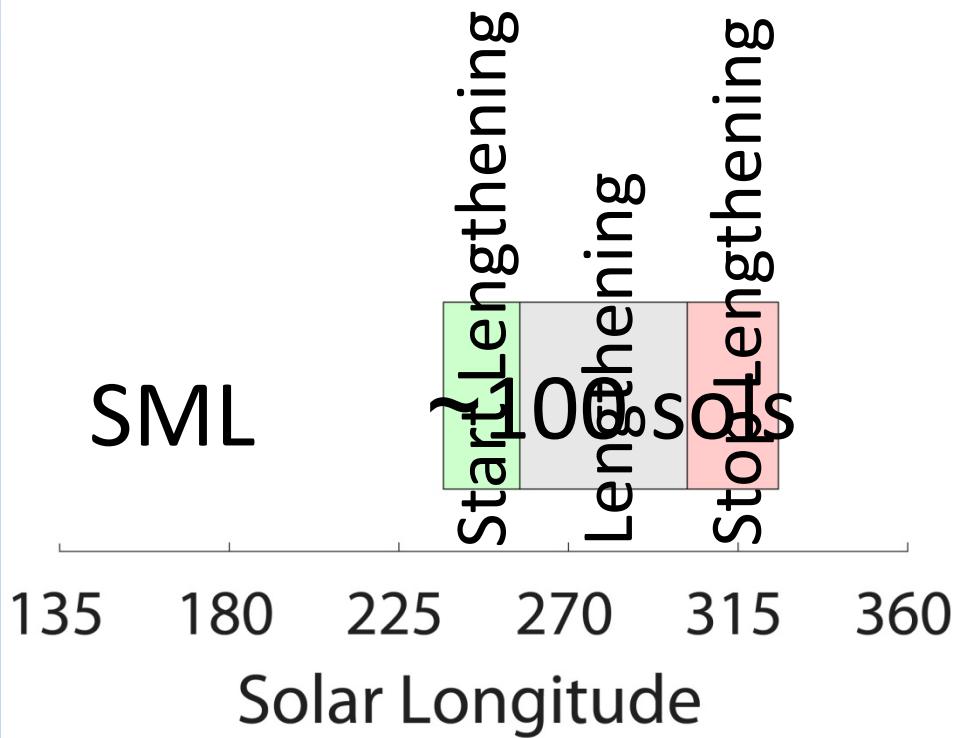


HiRISE images  
RSL sites  
Landing Sites &  
Habitation Zone



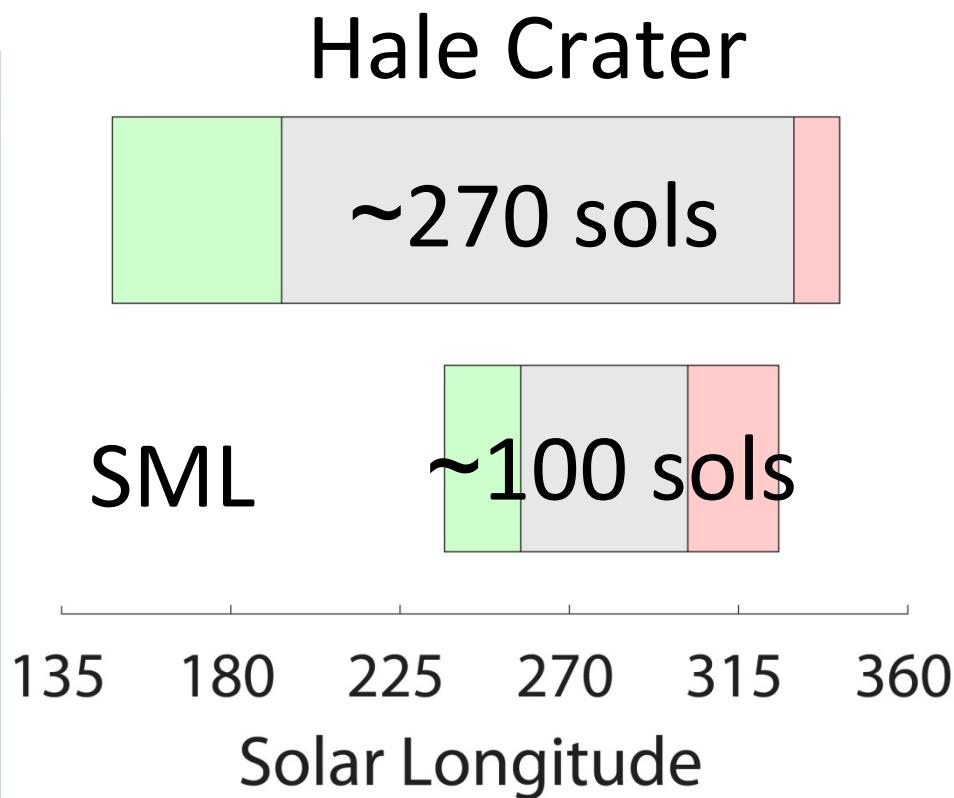
# RSL Properties

- Hale crater RSL are anomalous compared to SML RSL



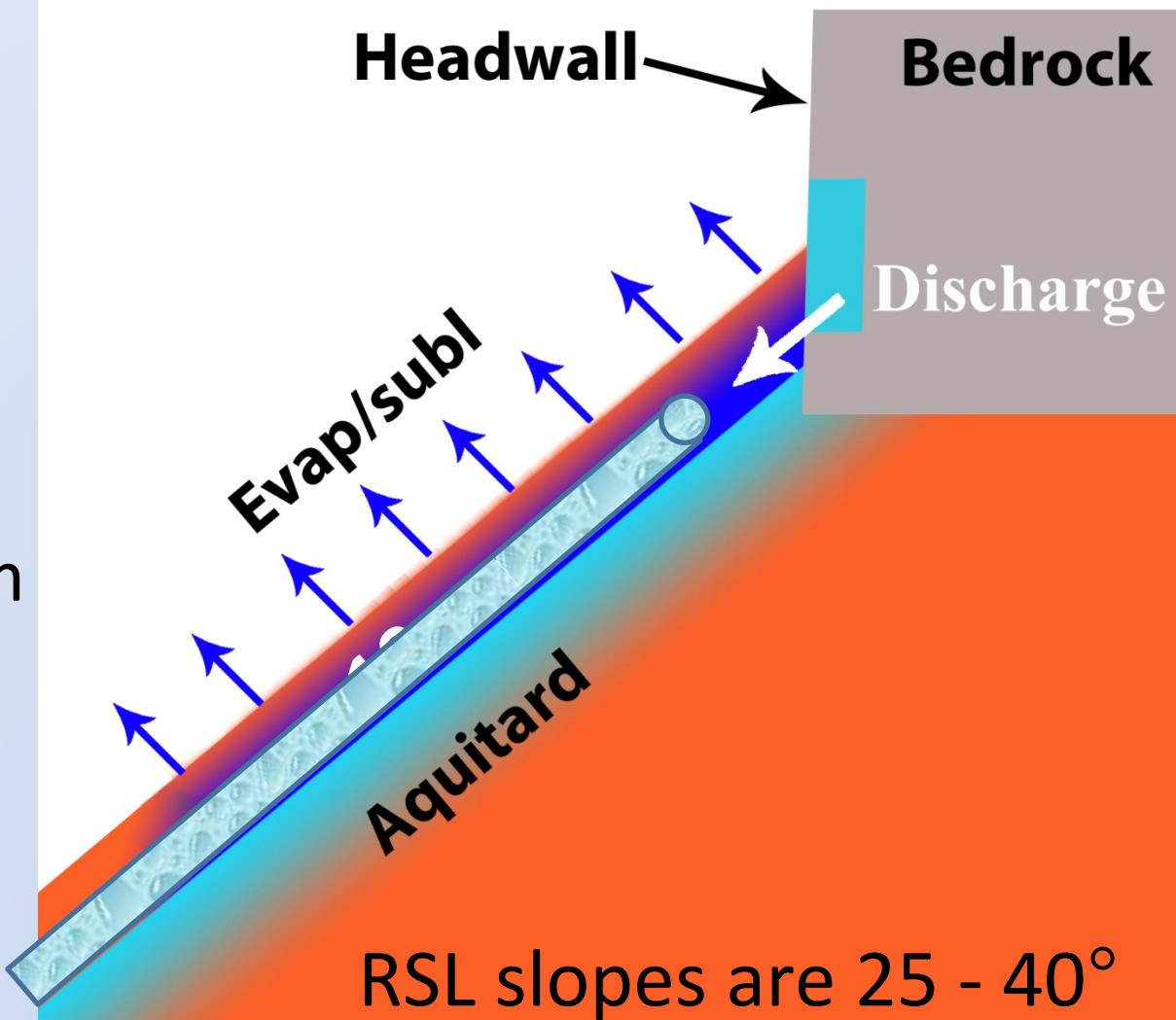
# RSL Properties

- Hale crater RSL are anomalous
- Duration is 2.7x longer
- Higher concentration of brine
- Thermophysical modeling indicates habitability (i.e., freezing temp of 269-247 K)



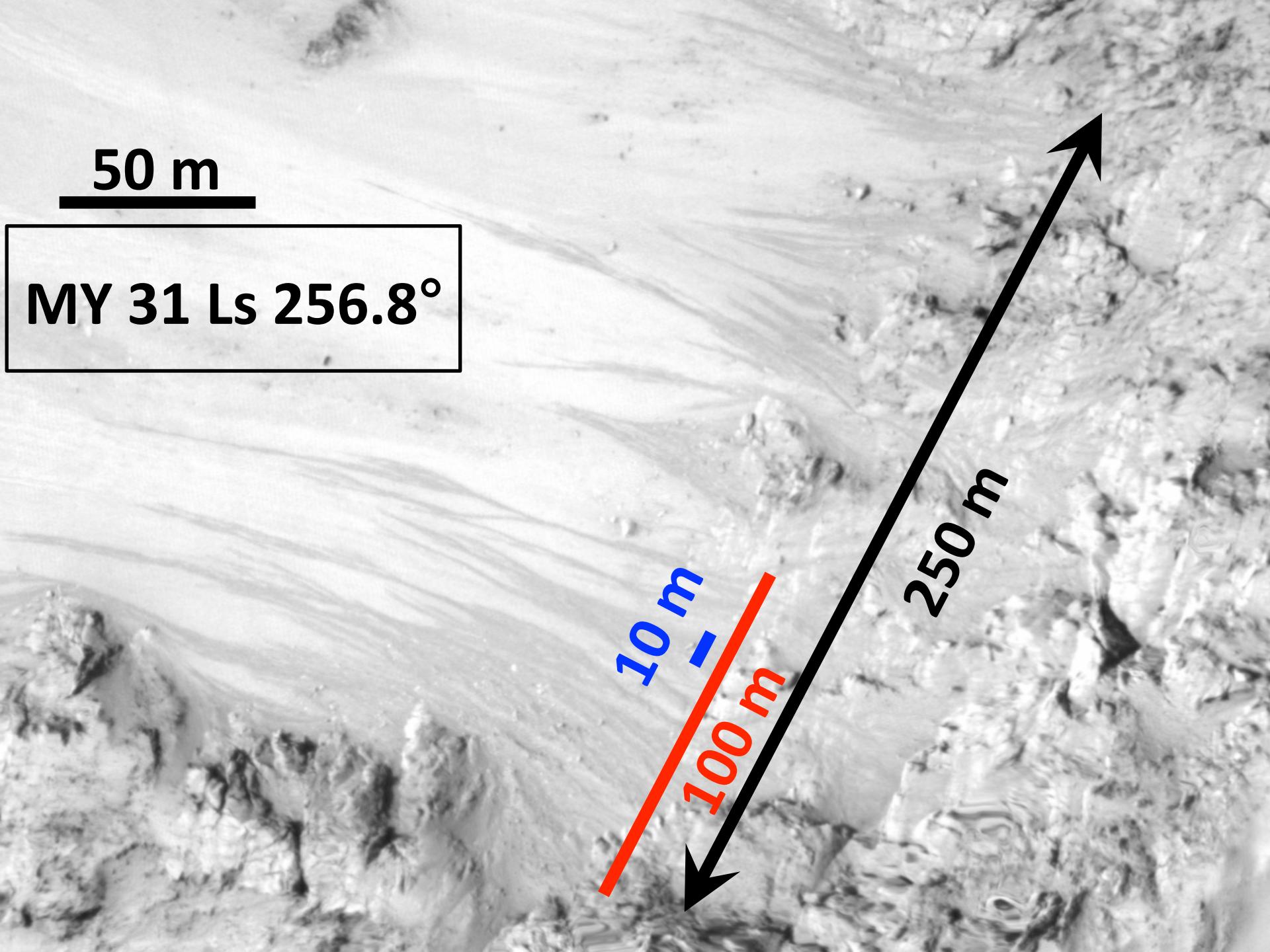
# Tap RSL

- Water budget estimate is  $>1\text{-}10 \text{ m}^3$  per m of headwall per yr (Grimm et al., *Icarus*, 2014)
- 100 MT you need 10-100 m of headwall



RSL slopes are 25 - 40°

*Not to scale*



50 m

MY 31 Ls 256.8°

10 m  
-  
100 m

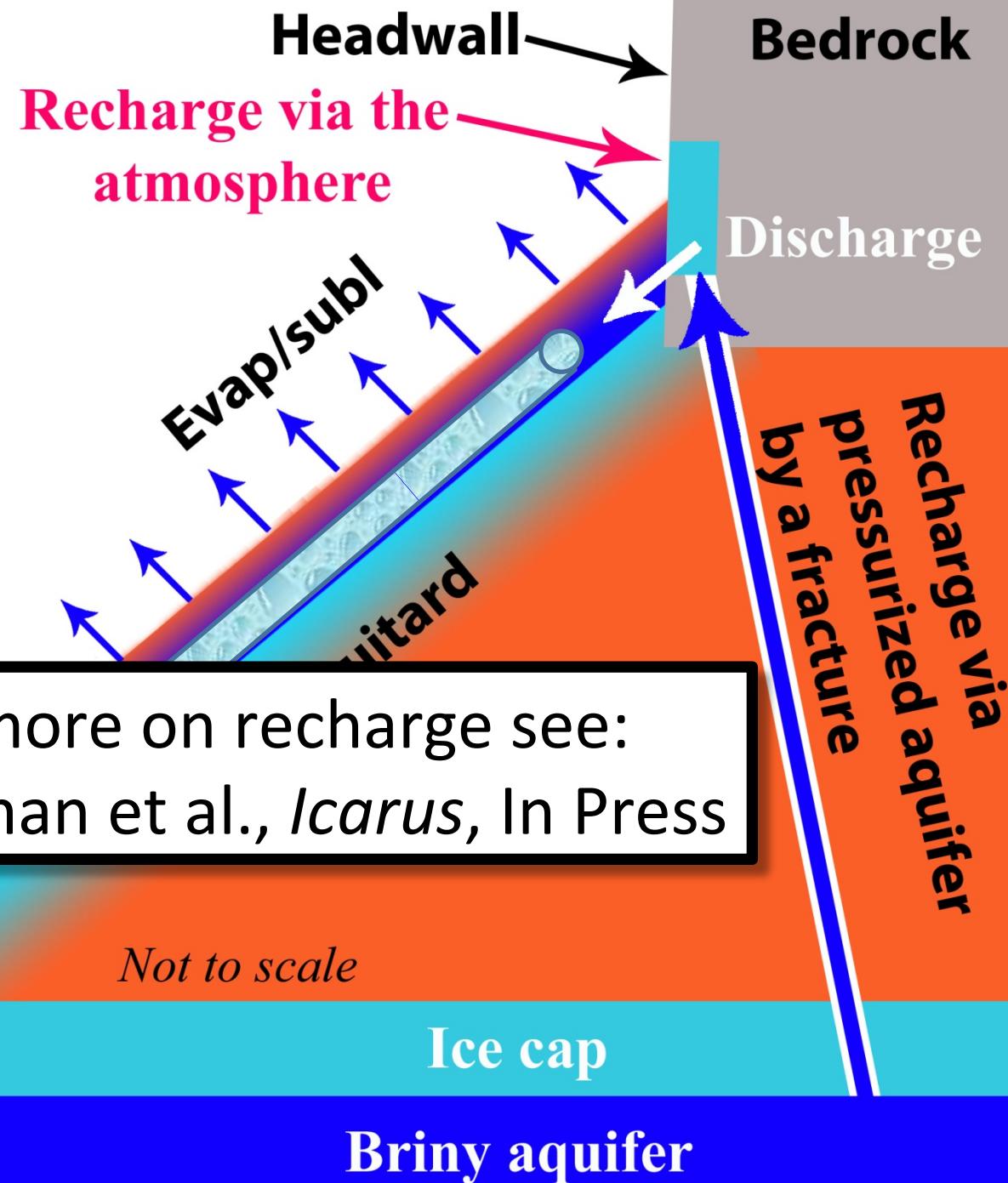
250 m

# Tap RSL

- Water budget estimate is  $>1\text{-}10 \text{ m}^3$  per m of headwall per yr (Grimm et al., *Icarus*, 2014)

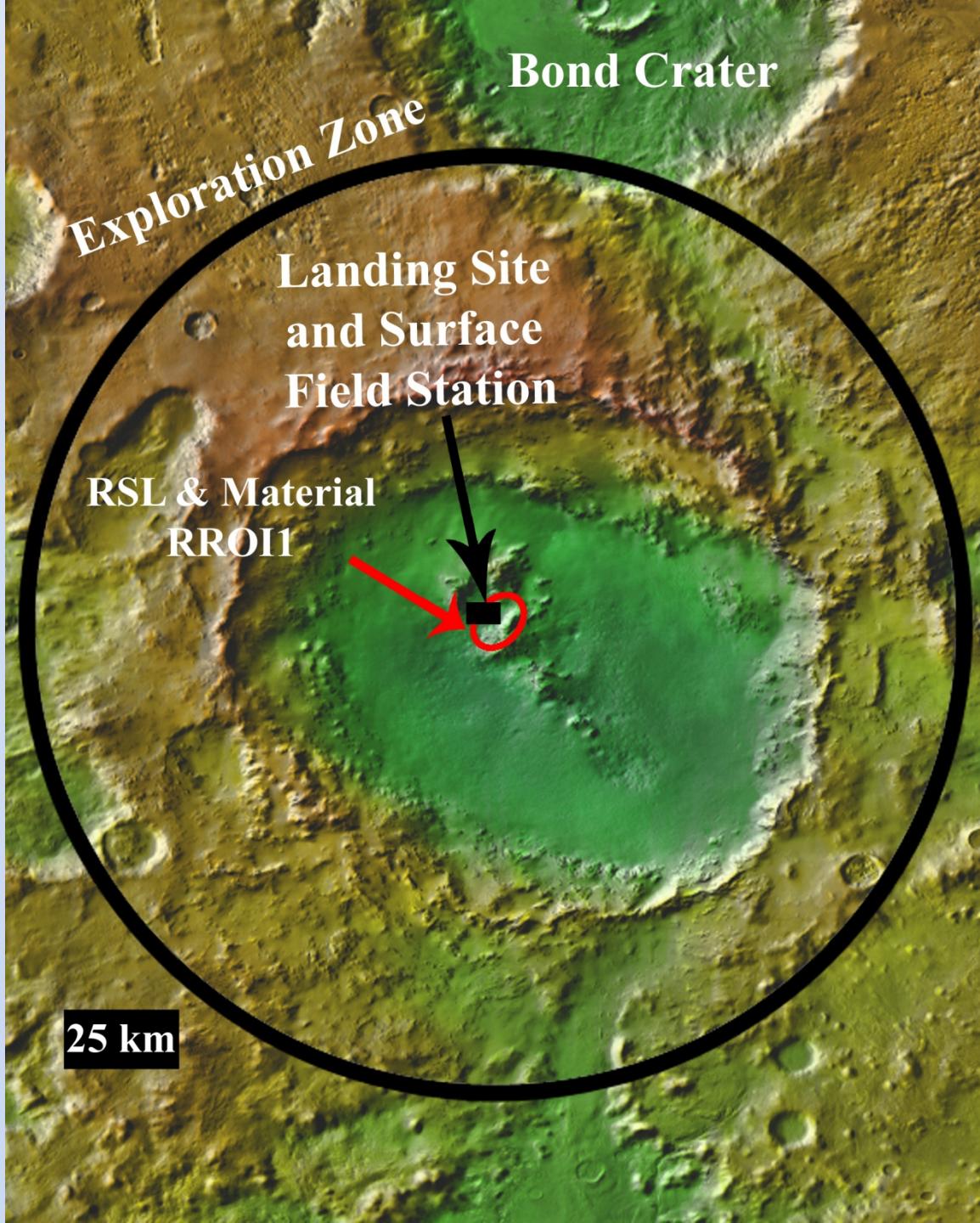
For more on recharge see:  
Stillman et al., *Icarus*, In Press

- 100 MT you need 10-100 m of headwall



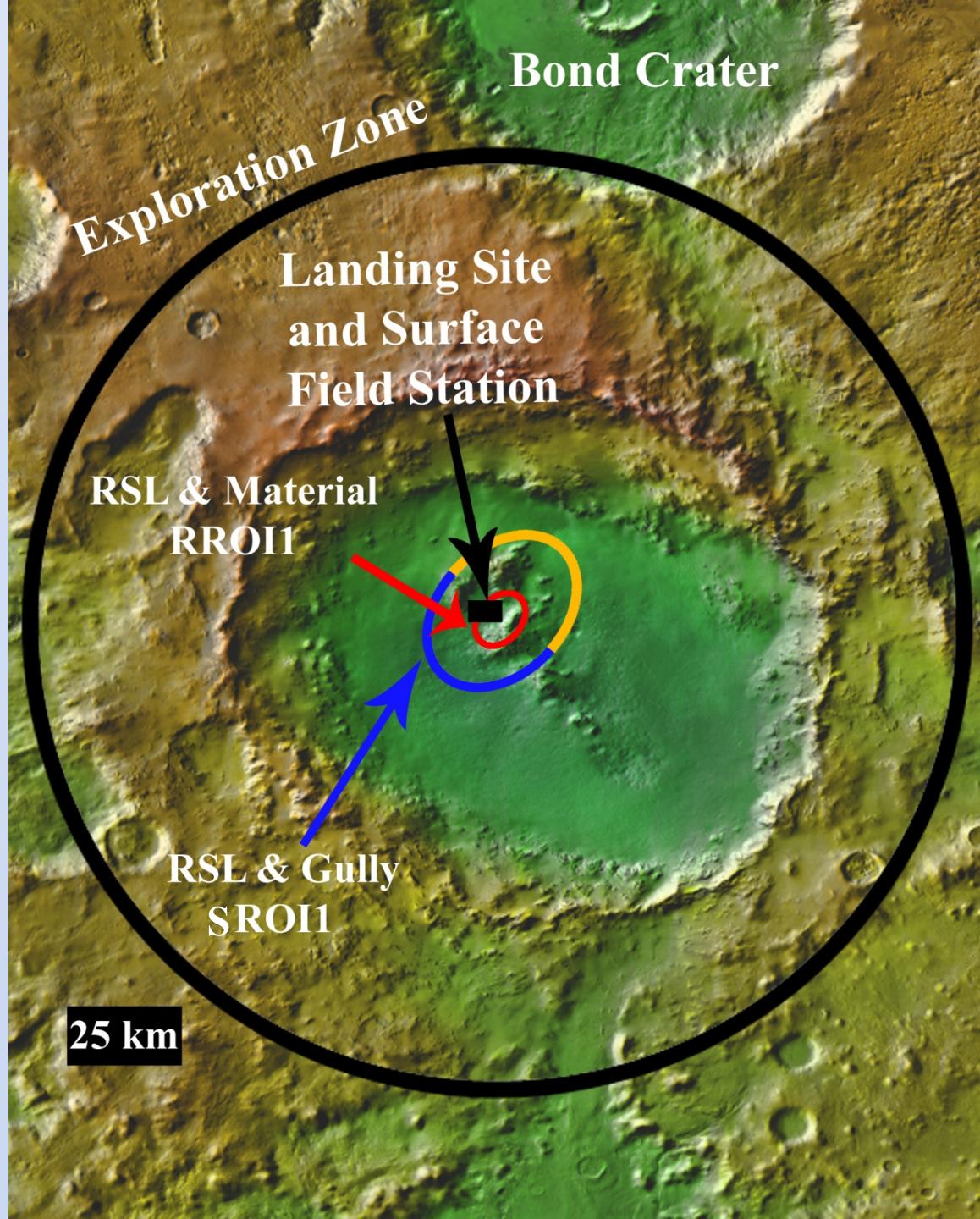
# RSL & Material Resource ROI1

- RSL Resource ROI - NW- and W-facing slopes
- Material Resource ROI - Scree slopes



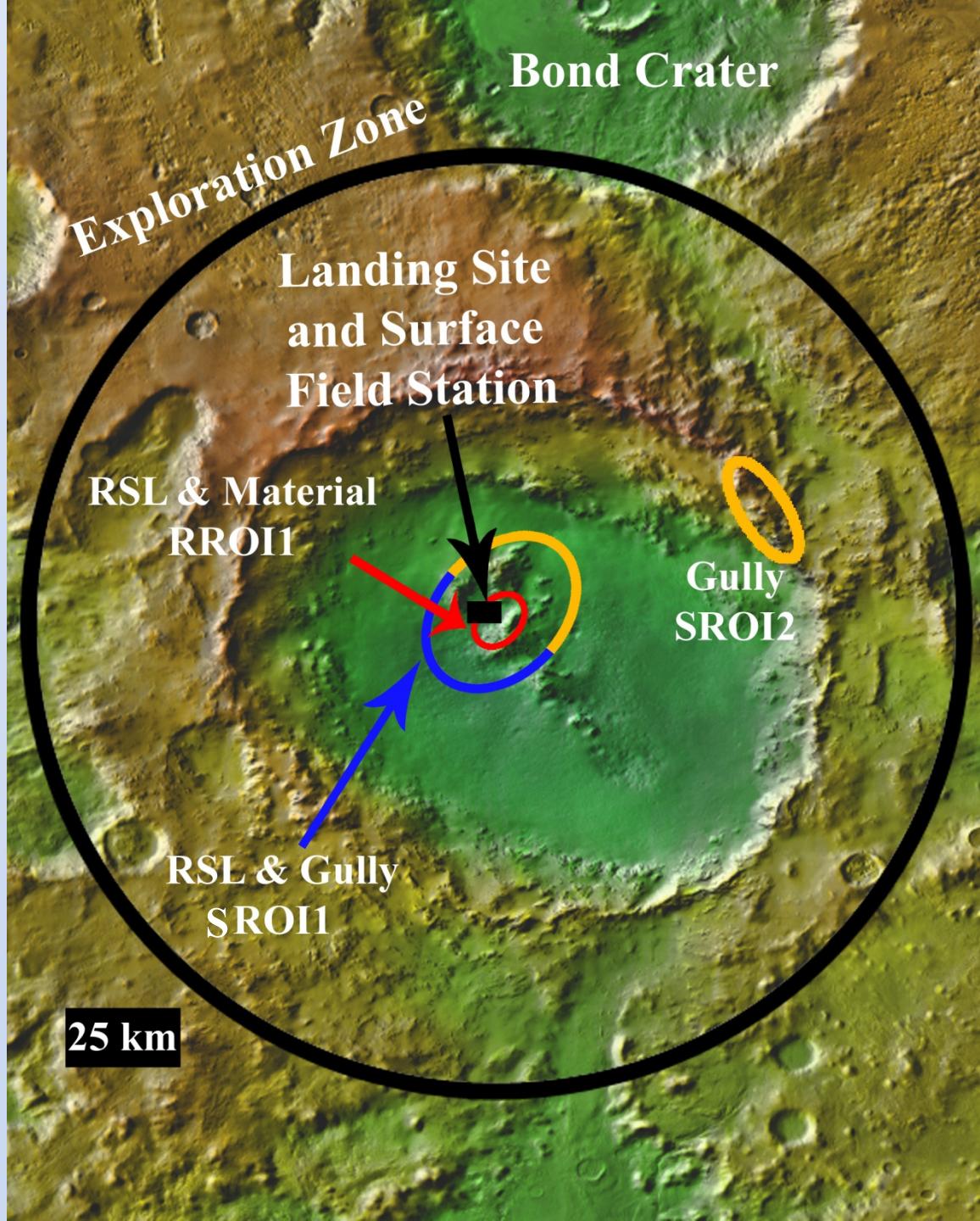
# RSL & Gully SROI1

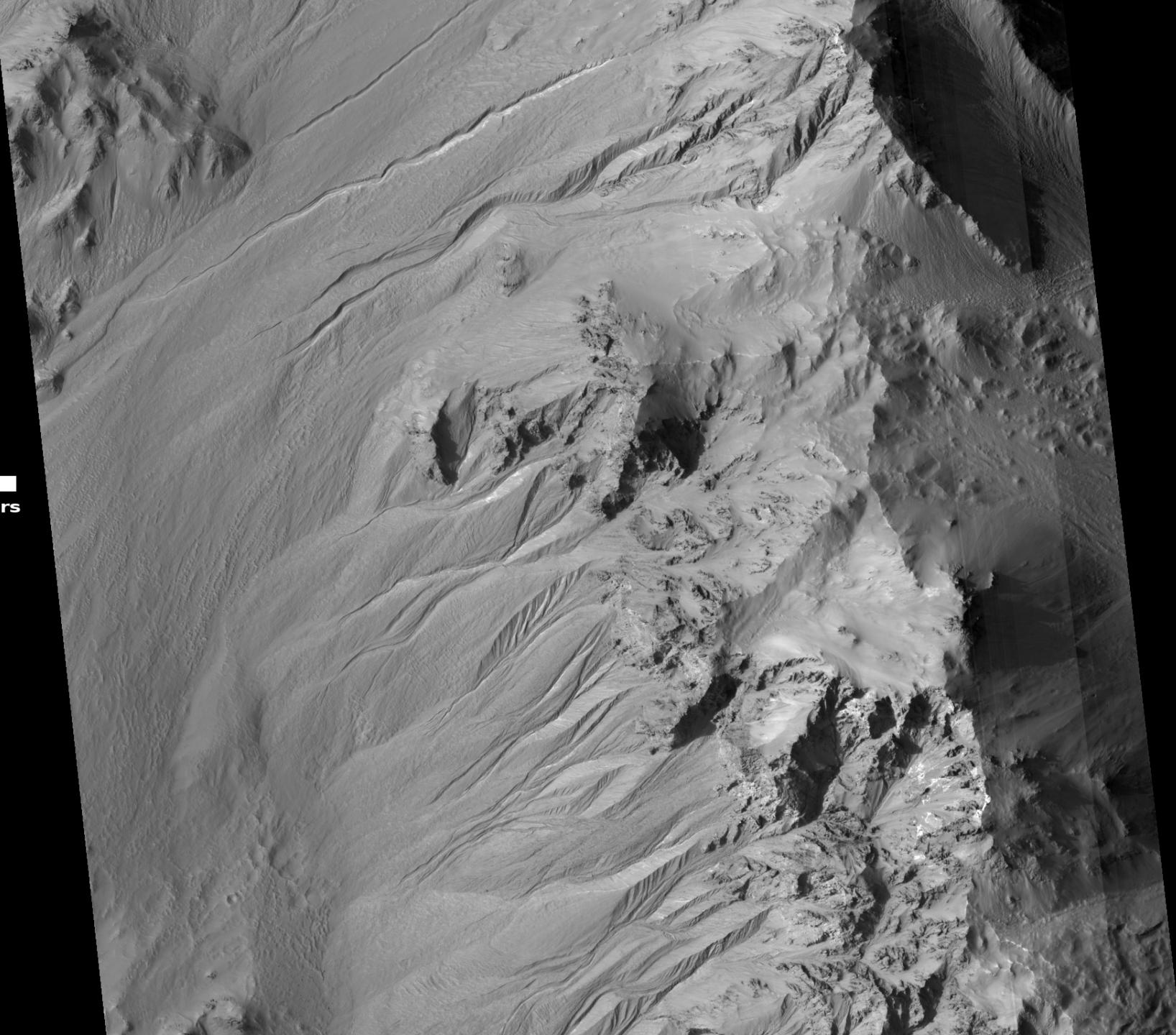
- Science of pristine RSL



# Gully SROI2

- When and how (water or CO<sub>2</sub>) were these originally carved?

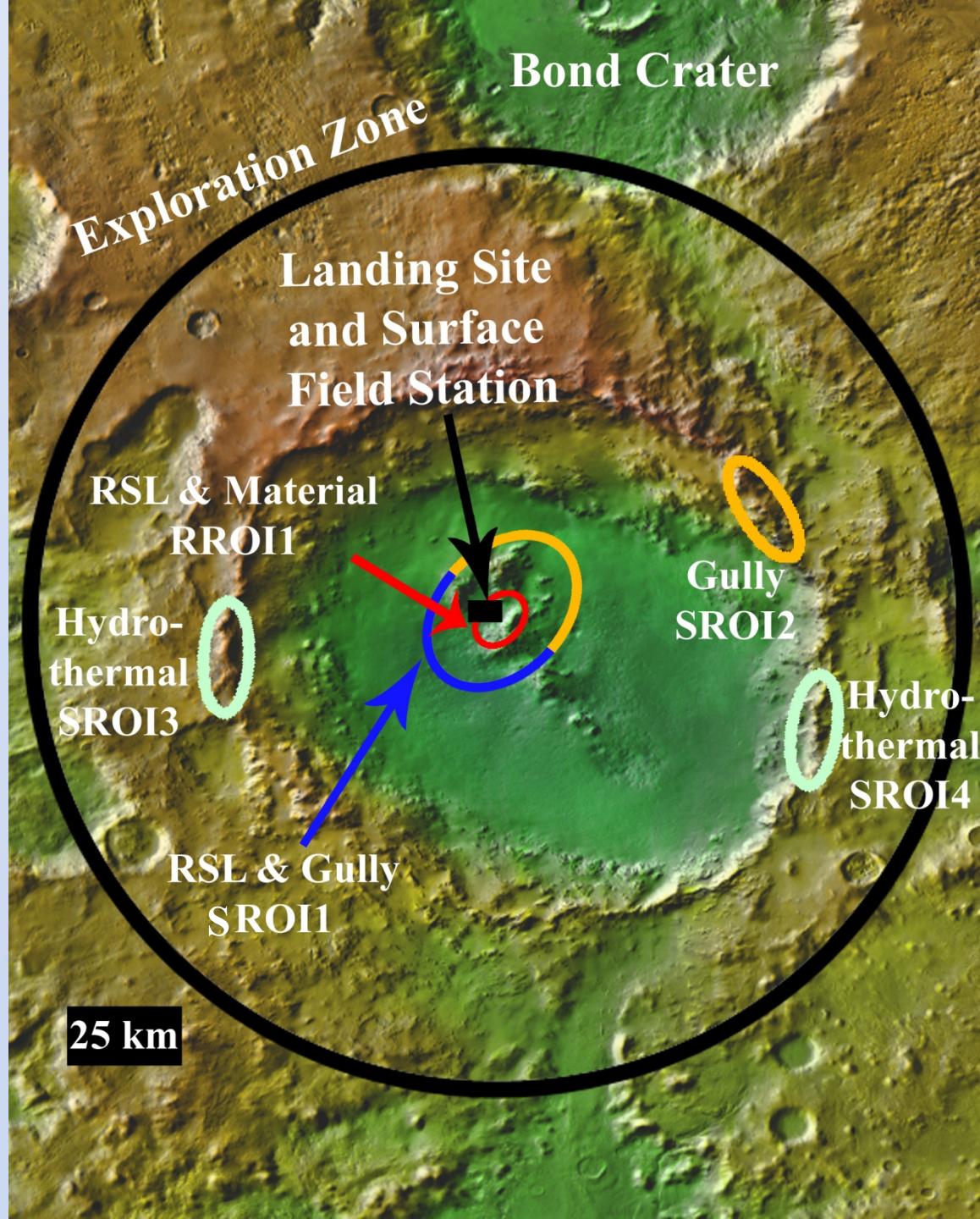




500 meters

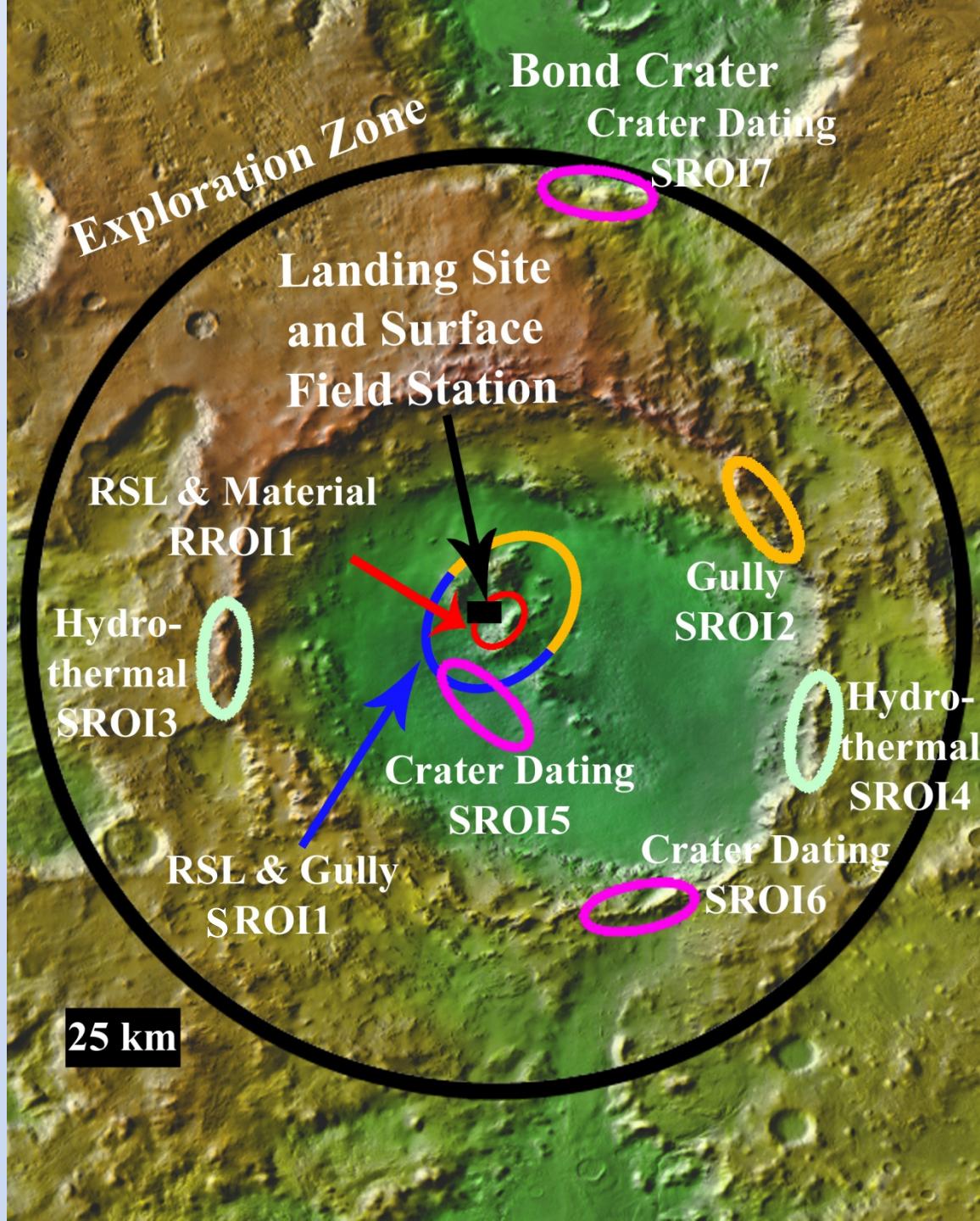
# Hydrothermal SROI3, 4

- Spectral evidence of hydrothermal alteration (Dohm et al., *Icarus*, 2015)
- May have created zones of habitability

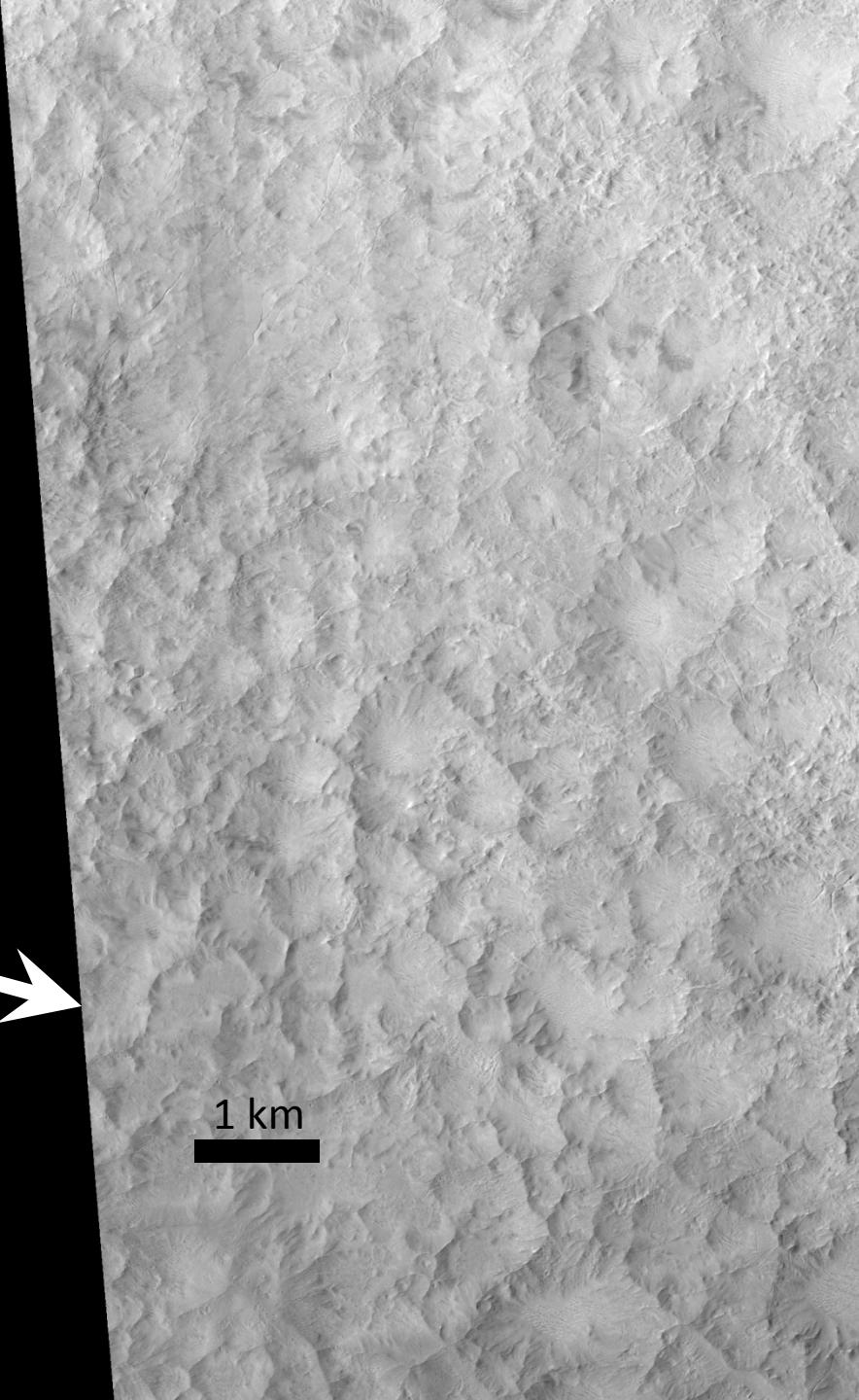
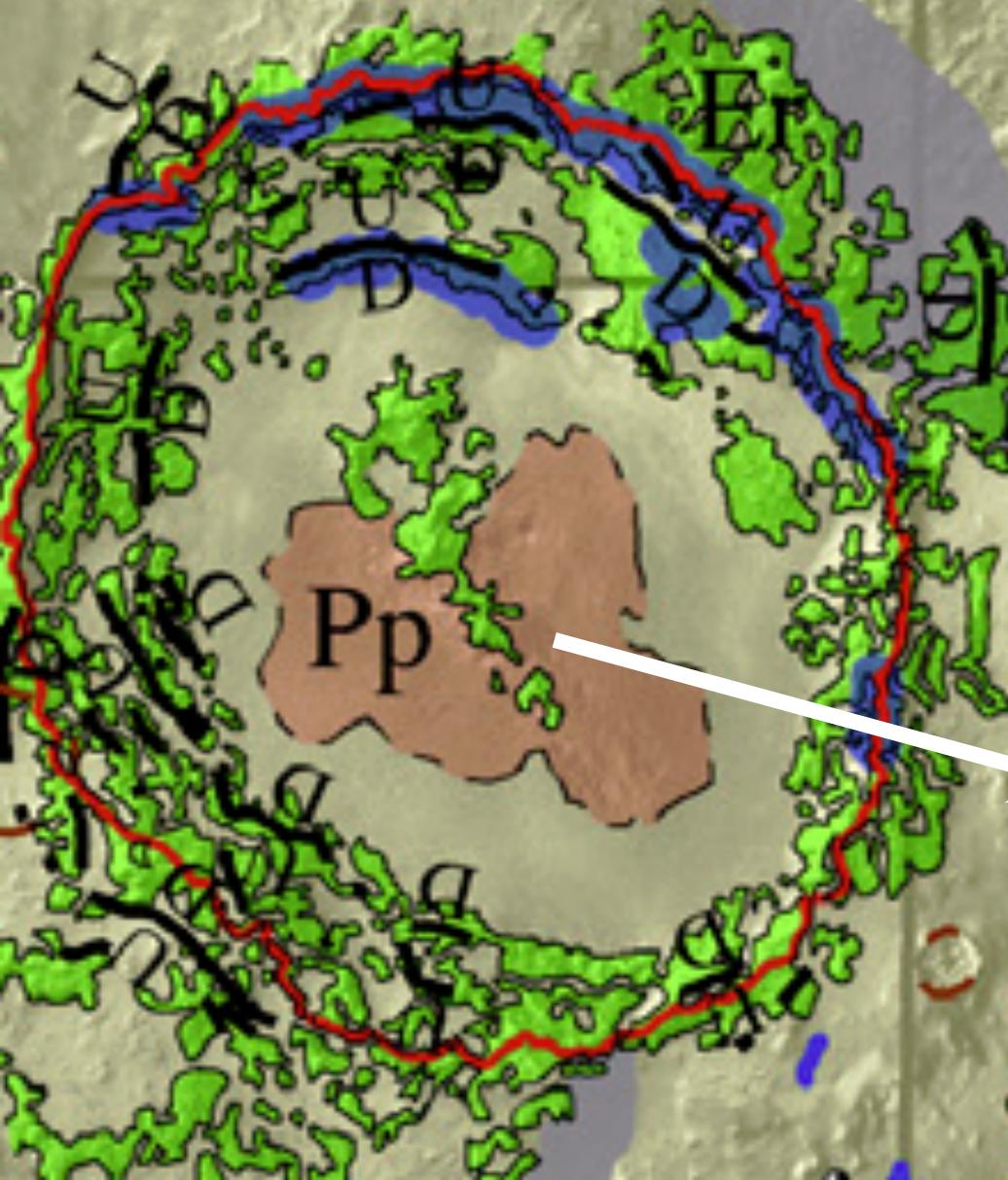


# Crater Dating

- SROI5, 6, 7
  - Calibrate crater counts to martian chronology
  - Shocked date of Hale, Bond, and Argyre craters
  - Best to date melt pond via drilling (possibly melted and pitted material)

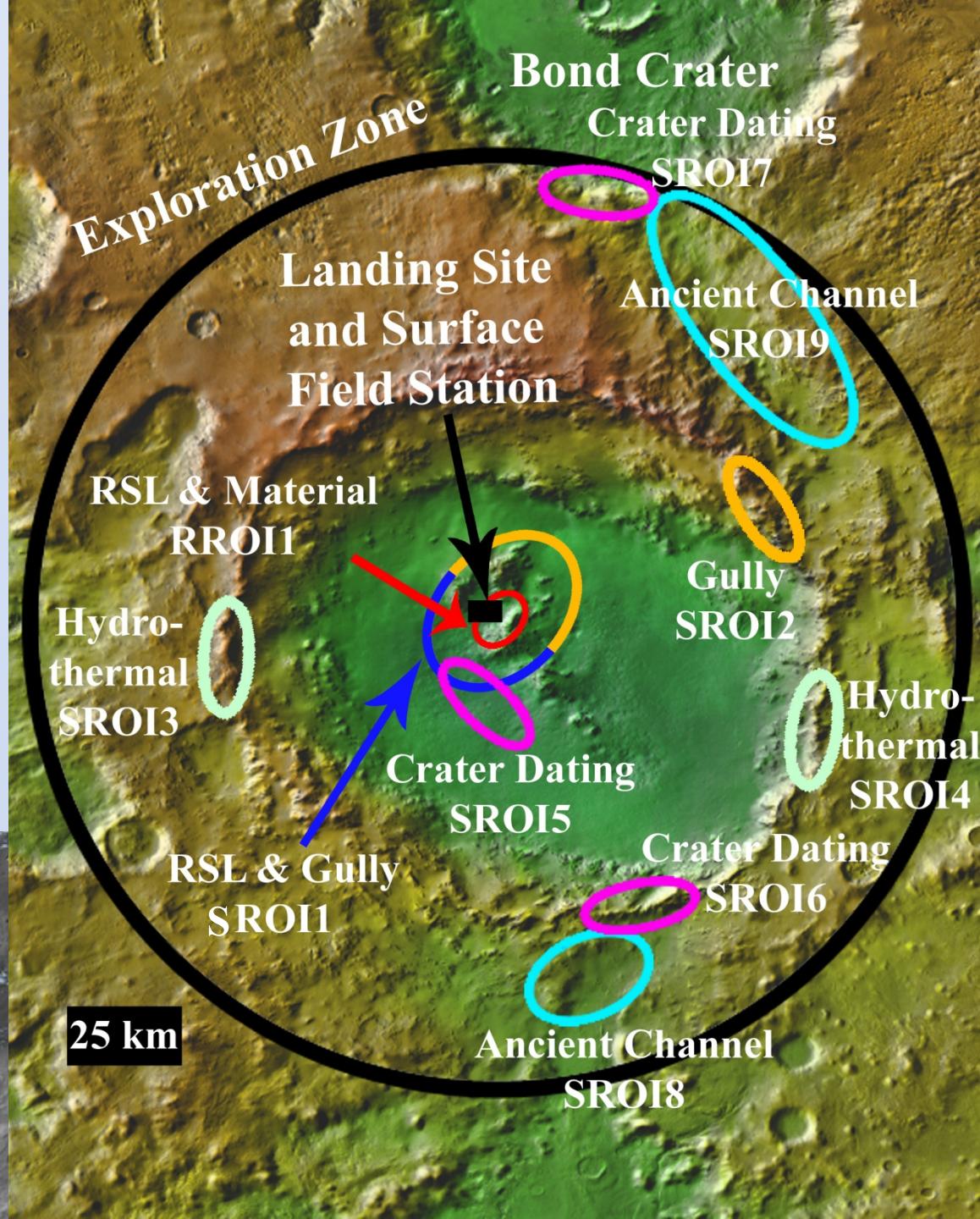
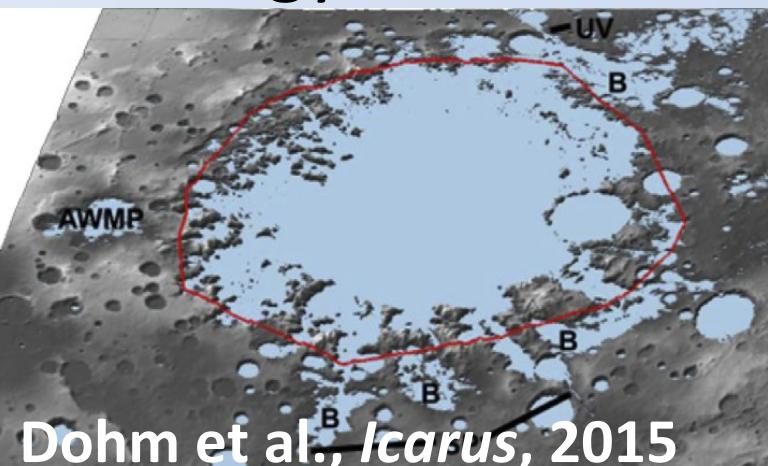


# Ponded and Pitted



# Ancient Channel SROI8,9

- Fluvial modification via Hale impact
- Did the ULM connect to Argyre?



Science ROI Rubric							
Science Site Criteria	Site Factors						
	SROI1	SROI2	SROI3,4	SROI5,6,7	SROI8,9	RROI1	
	●	●	●		●	●	
	○				○	○	
	●	●	●		●	●	
			○			●	
	●	●	●	●	●	●	
	●				●	●	
		<p><b>Potential for past habitability</b></p> <p><b>Potential for present habitability/refugia</b></p> <p>Potential for organic matter, w/ surface exposure</p> <p><b>Noachian/Hesperian rocks w/ trapped atmospheric gases</b></p> <p>Meteorological diversity in space and time</p> <p>High likelihood of surface-atmosphere exchange</p> <p>Amazonian subsurface or high-latitude ice or sediment</p> <p>High likelihood of active trace gas sources</p> <p><b>Range of martian geologic time; datable surfaces</b></p> <p><b>Evidence of aqueous processes</b></p> <p><b>Potential for interpreting relative ages</b></p> <p>Igneous Rocks tied to 1+ provinces or different times</p> <p>Near-surface ice, glacial or permafrost</p> <p>Noachian or pre-Noachian bedrock units</p> <p>Outcrops with remnant magnetization</p> <p>Primary, secondary, and basin-forming impact deposits</p> <p>Structural features with regional or global context</p> <p>Diversity of aeolian sediments and/or landforms</p>					
		<p>7.0</p> <p>0.2</p> <p>5.0</p> <p>0.1</p> <p>10.0</p> <p>2.0</p> <p>2.1</p> <p>0.0</p> <p>3.2</p> <p>7.0</p> <p>5.0</p> <p>0.0</p> <p>2.1</p> <p>4.0</p> <p>0.10</p> <p>10.0</p> <p>7.0</p> <p>2.0</p>					
		<b>EZ SUM</b>					

# ISRU and Civil Engineering



# Resource ROI Rubric Site Factors

ets First Order Criteria (Latitude, Elevation, Thermal Inertia)

**Potential for ice or ice/regolith mix**

**Potential for hydrated minerals**

**Quantity for substantial production**

**Potential to be minable by highly automated systems**

**Located less than 3 km from processing equipment site**

**Located no more than 3 meters below the surface**

**Accessible by automated systems**

ential for multiple sources of ice, ice/regolith mix **and** hydrated minerals

Distance to resource location can be >5 km

Route to resource location must be (plausibly) traversable

**~50 sq km region of flat and stable terrain with sparse rock distribution**

**1–10 km length scale: <10°**

**Located within 5 km of landing site location**

Located in the northern hemisphere

Evidence of abundant cobble sized or smaller rocks and bulk, loose regolith

Utilitarian terrain features

Low latitude

No local terrain feature(s) that could shadow light collection facilities

Access to water

Access to dark, minimally altered basaltic sands

**Potential for metal/silicon**

**Potential to be minable by highly automated systems**

**Located less than 3 km from processing equipment site**

**Located no more than 3 meters below the surface**

**Accessible by automated systems**

Potential for multiple sources of metals/silicon

Distance to resource location can be >5 km

Route to resource location must be (plausibly) traversable

SROI1	SROI2	SROI3,4	SROI5,6,7	SROI8,9	RROI1	EZ SUM
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● ● ● ● ● ● 10.0

● ○ ? ? ? ● 2.1

● ● ● 4.0

● ● 2.0

○ ● 0.2

● ● 1.0

● ○ ○ ○ ○ ● 4.3

○ ● 0.2

● ? ● ? ? ● 3.0

● ● ● ● ● ● 1.0

● ● ● ● ● ● 10.0

● ● ● ● ● ● 5.0

● ● ● ● ● ● 5.0

● ● 1.0

● ● 0.0

● ● ● ● ● ● 10.0

○ ○ 0.3

● ● 0.0

● ● ● 3.0

● ● 2.0

● ● 1.0

○ ○ ○ ○ ○ ○ 0.10

○ ○ ○ ○ ○ ○ 0.10

● ● 1.0

○ ○ ○ ○ ○ ○ 0.10

○ ○ ○ ○ ○ ○ 0.10

○ ○ ○ ○ ○ ○ 0.9

● ● 2.0

● ● ● ● ● ● 10.0

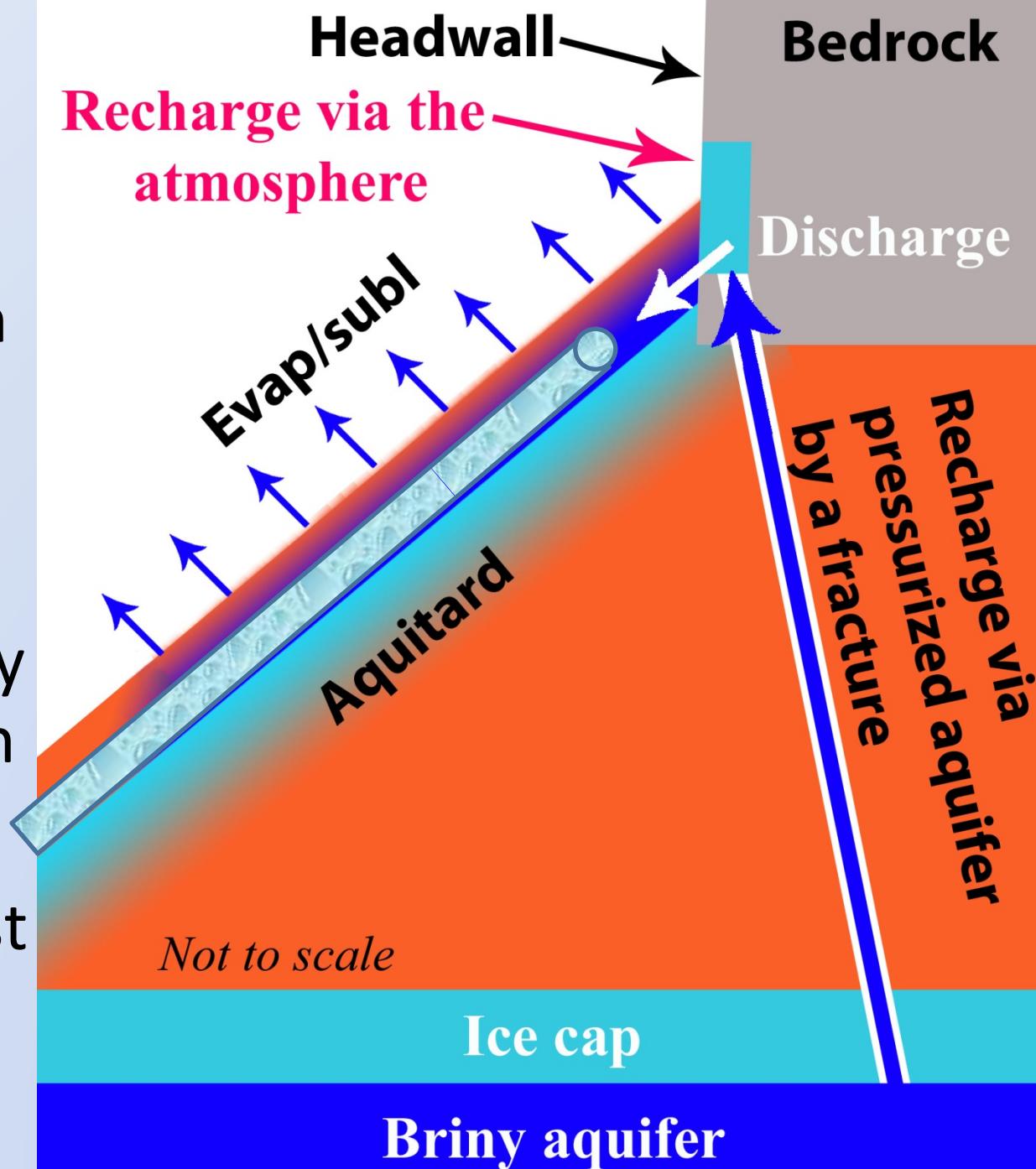
# Highest Priority EZ Data Needs

- RSL over all the central peaks?
  - HiRISE images
- Constrain RSL start
  - HiRISE images
- Topography over the entire central part of Hale and at the two passes
  - HiRISE or CTX DTMs
- More hydrothermal alteration?
  - CRISM



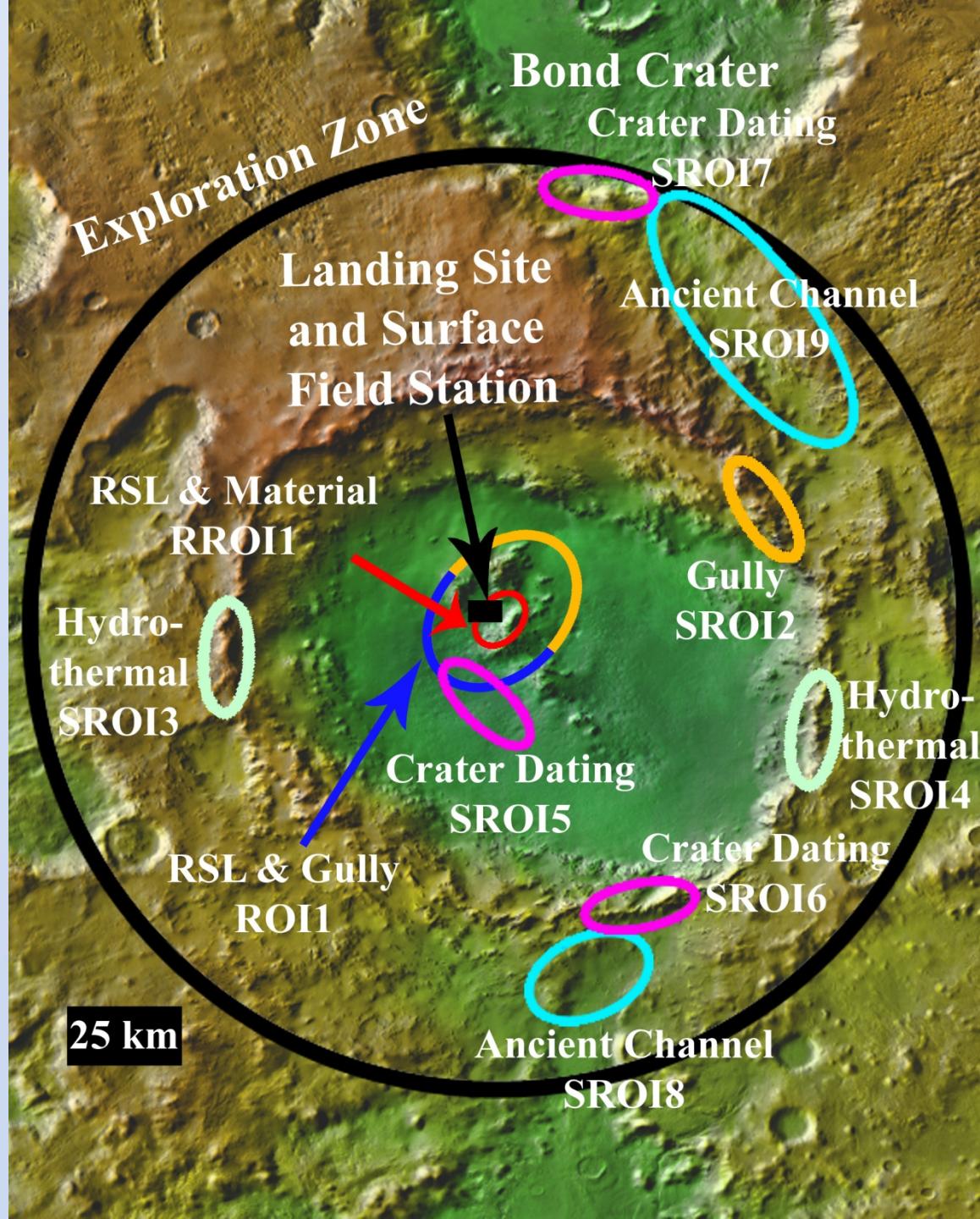
# RSL as a resource?

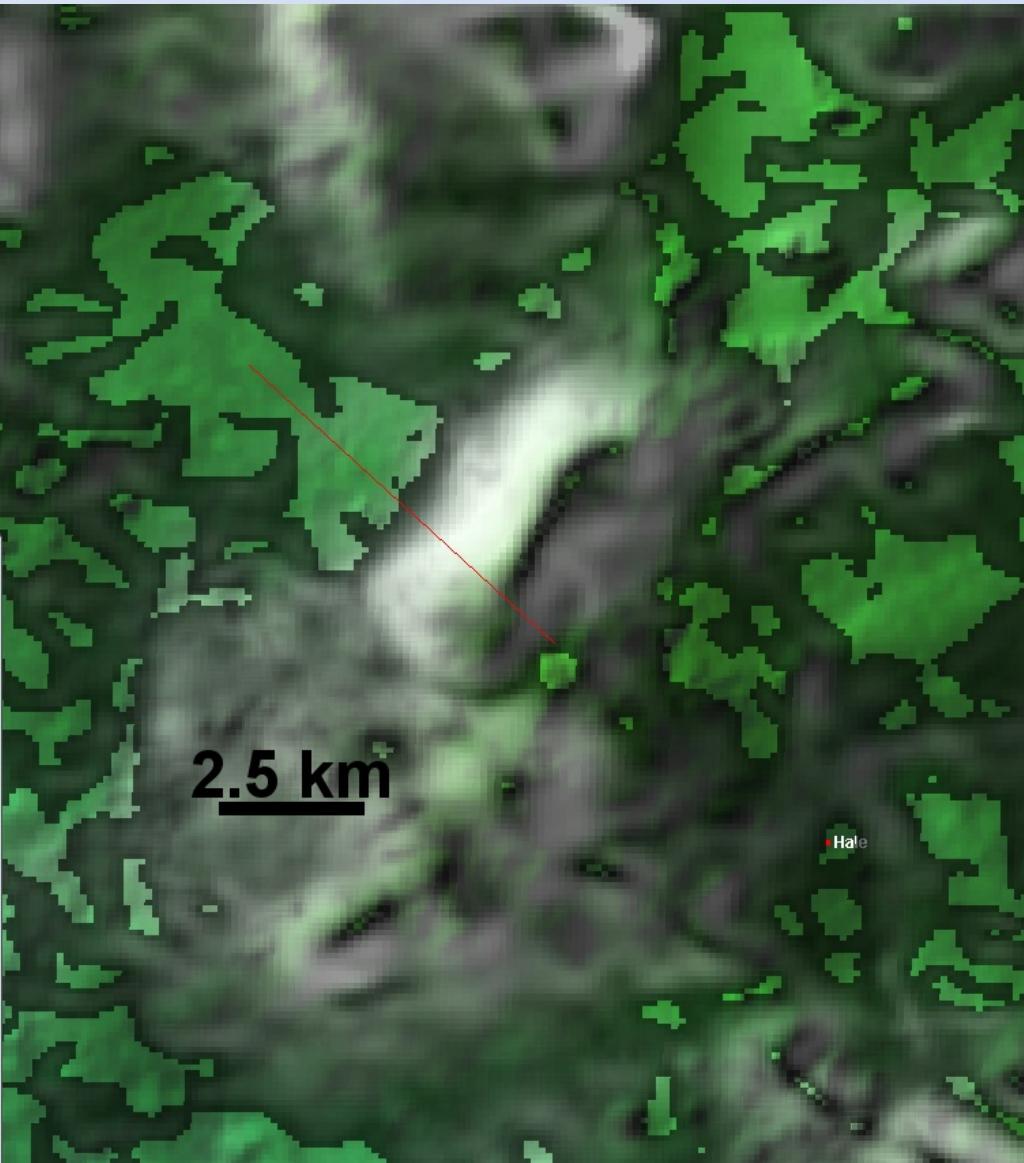
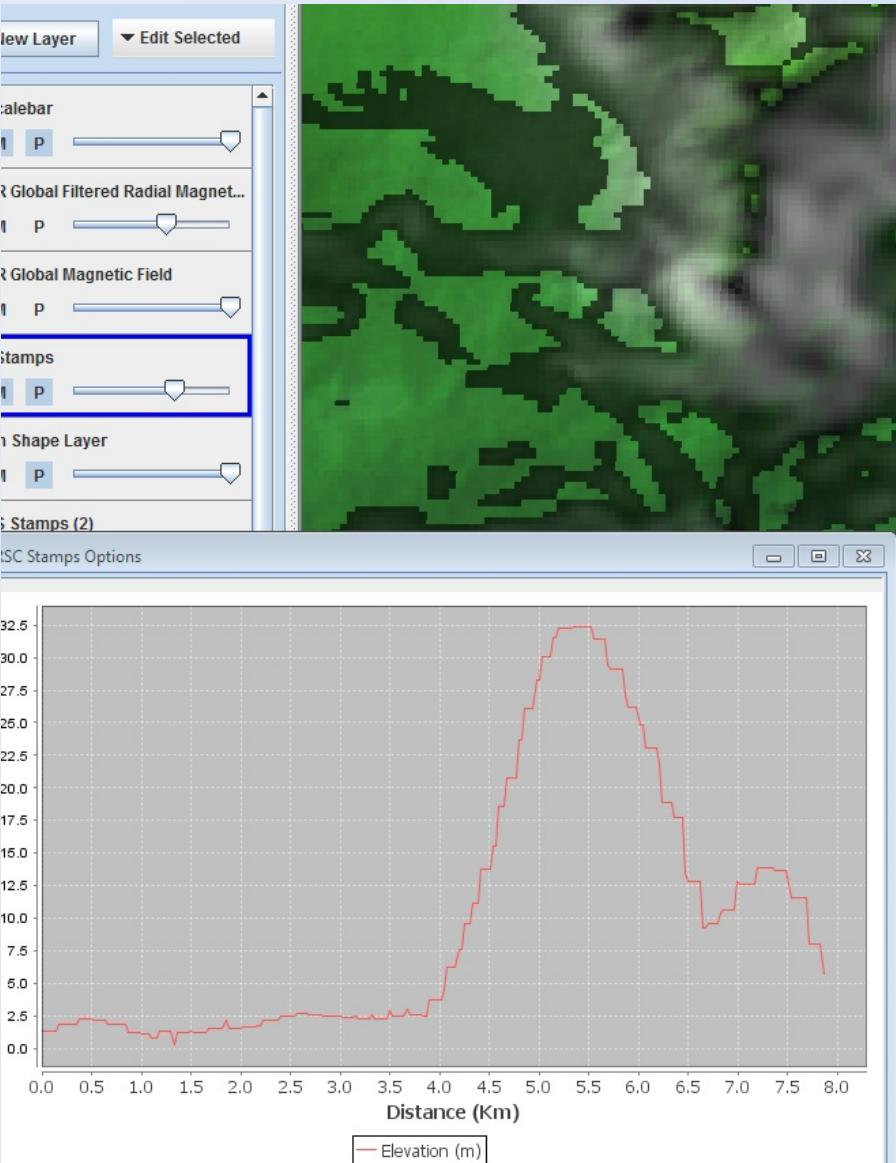
- Too uncertain right now
- Need more data and likely a new mission
- Are slopes just too steep?



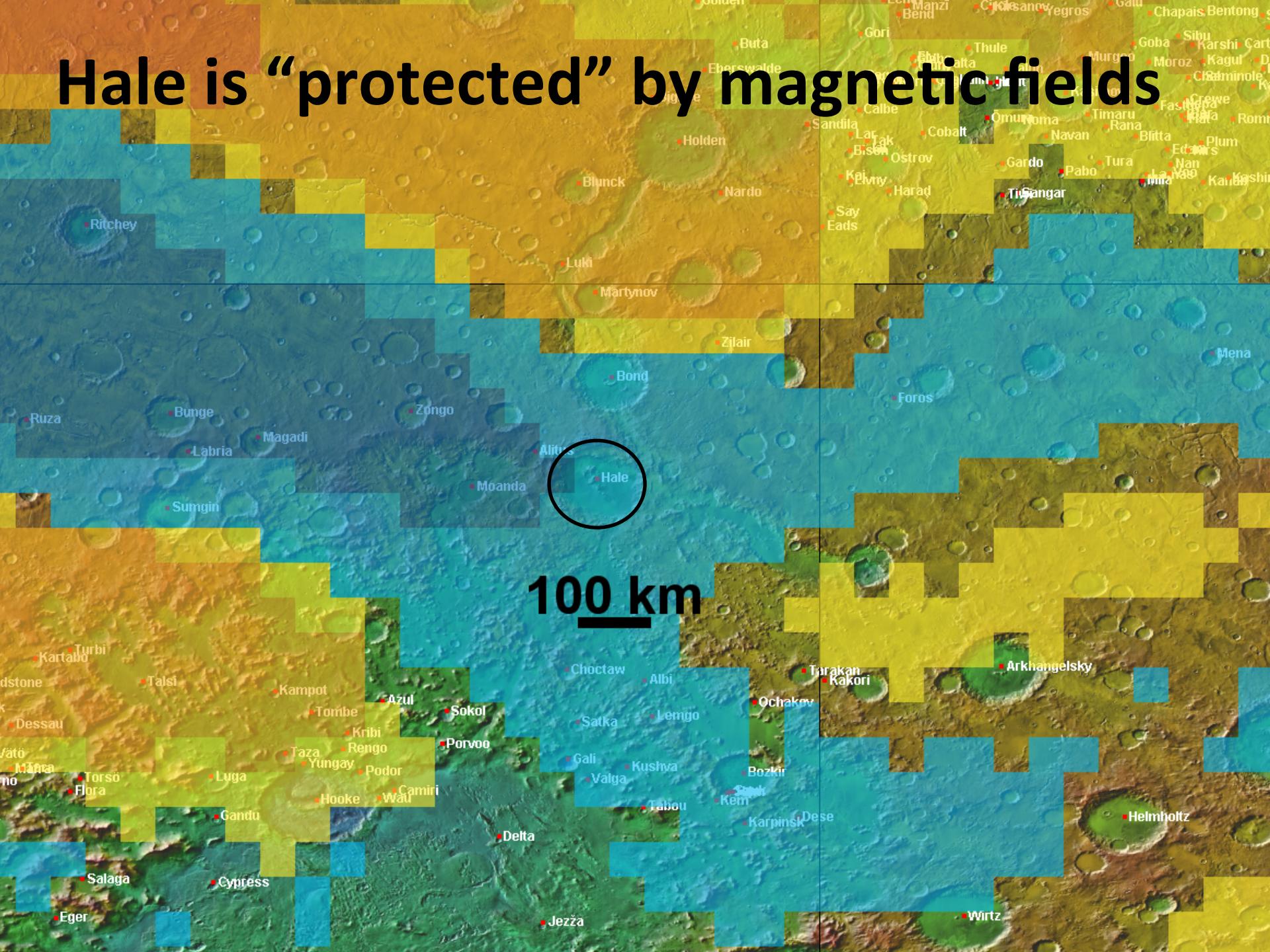
# Conclusion

- Minimize infrastructure for water extraction
  - Minimizes cost and risk





# Hale is “protected” by magnetic fields



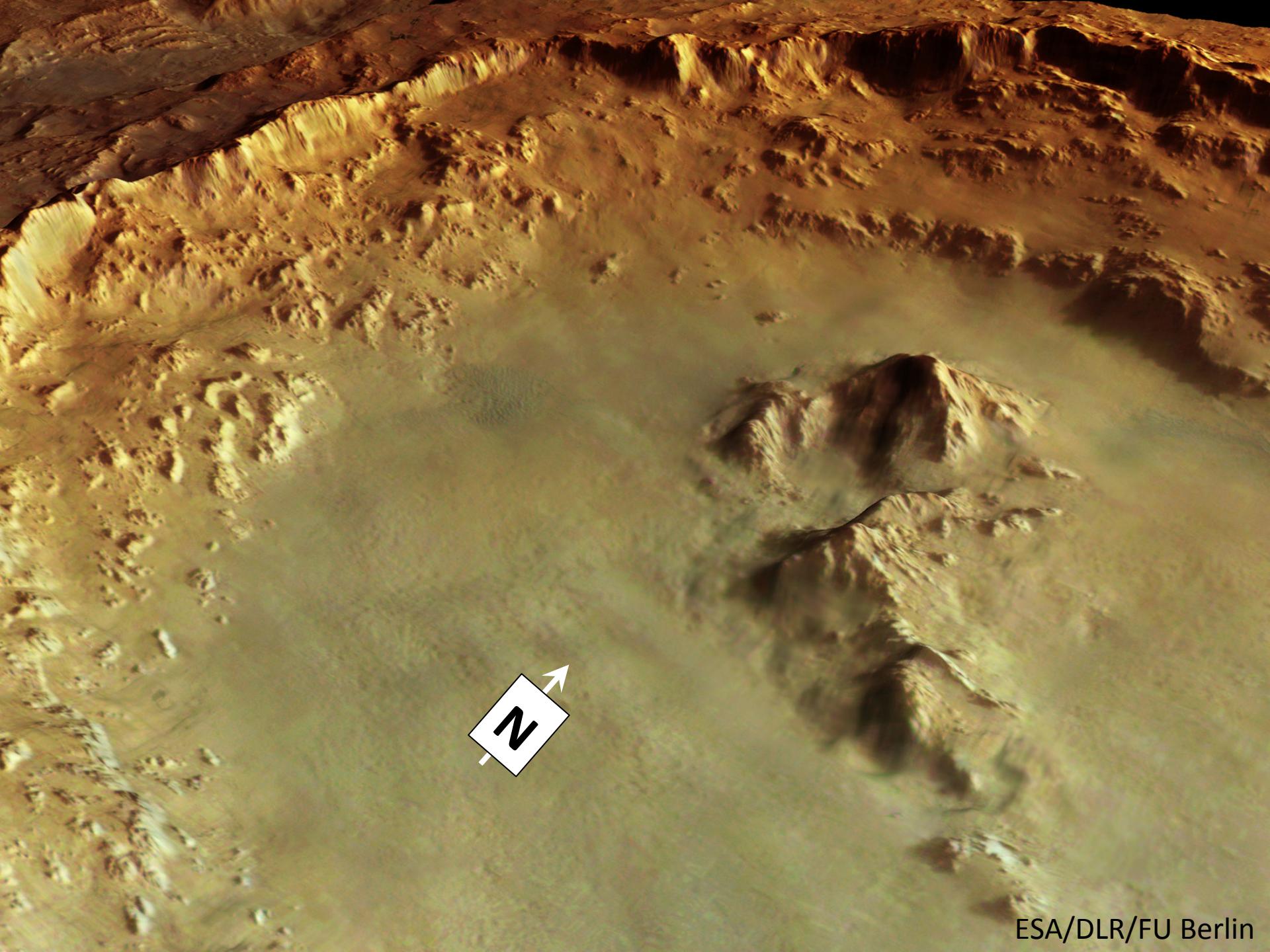
100 km

# Astrobiology

- Extant life – RSL ROI (A3)
- Characterize modern environment with high habitability – RSL ROI (A4)
- Past Life – RSL, Gullies, Hydrothermal, Ancient channels ROI (A1, A2)
- Characterize the exchange and cycling of H<sub>2</sub>O between the subsurface, surface, and atmosphere – RSL ROI (A5)

# Geoscience

- What was the source of ULM? – Ancient Channels ROI (C1)
- What is the date of the Hale Crater impact event and why was the subsurface so wet? – Ancient Channels and Age Dating ROIs (C1, C2)
- Date of Argyre, Hale and Bond craters (C1, C2)



ESA/DLR/FU Berlin

**50 m**

**MY 31 Ls 256.8°**

**50 m**

**MY 31 Ls 264°**  
**11 sols later**